MAIN RANGE GRANITE GEOTHERMAL POTENTIAL IN PENINSULAR MALAYSIA

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ABSTRACT

There are at least 51 sites of thermal springs in the Peninsular Malaysia have been recognized and about 20 sites are selected to be studied on their sub-surface reservoir temperatures using the available previous data collected by the Minerals and Geoscience Department Malaysia (JMG) since 1980s. The previous data available from the 23 sites i.e. surface temperature, geology, chemistry of thermal waters, etc. have been analysed, to evaluate the sub-surface reservoir temperatures in granitic systems.

The range of reservoir temperatures for the overall selected thermal springs, were calculated by using the T_quartz, T_Na/K and T_Na-K-Ca methods. Generally, the reservoir temperatures range from 105.3°C - 154.2°C (Tquartz), 127.3°C - 199.7°C (T Na/K) and 115°C - 208°C (T Na-K-Ca). Result of the reservoir temperatures estimation by using the T chalcedony method are generally low and does not reflect the geothermal systems probably due to dilution effect during the ascent of geothermal fluids. Therefore the T quartz is used, together with the cations geothermometers for estimation of the reservoir temperatures. The findings on the reservoir temperatures are encouraging and warrants for further geothermic investigations, however drilling may confirm the exact temperatures.

Keywords: Geochemistry, geothermometer, granite

1.0 INTRODUCTION

1.1 Background

There was no previous study done to assess the geothermal potential in Peninsular Malaysia for power generation by the earlier workers. Studies were only focused on the occurrence of hot springs, the hot springs water quality, and their suitability for tourism. The only study related to the geothermal potential was carried by Ho (1979). He had preliminarily worked on geothermometric in part the states of Perak and Kedah, to determine the sub-surface temperature of the thermal springs based on silica content in the geothermal water. He reported the results obtained for reservoir temperatures were ranged from 125°C to 166°C. No other similar work has been done.

Generally, the thermal springs occur within the granite batholiths of the Main Range, which occupies the western half of Peninsular Malaysia. Their occurrences are mainly related to the major fault zones post magmatic activities of the intrusive granites. The thermal springs occur in similar direction of the major faults, mainly manifested as thermal springs (Figure 1). The faults are seems to be a deep seated faults.

Current scope of studies was mainly focused on the evaluation of initial reservoir temperatures based on available data at the Minerals and Geoscience Department Malaysia (JMG). Further detailed investigations on geologic structures using geophysical techniques such as gravity survey, resistivity or magneto-telluric soundings are recommended.

Out of the 51 localities thermal springs identified in Peninsular Malaysia, including 6 localities in Lojing, Kelantan area, and in Hulu Slim area, the average discharge rate of these springs were between 2 and 6 litres, and one site was about 20 litres(Tambun Perak), whereas the surface temperatures were ranging from low to high temperatures (boiling water), with near neutral pH.

A total of about 20 thermal spring localities were selected forstudies on its reservoir temperatures. Previous preliminary geothermometric works were done by C.S. Ho (1979), in Perak and Kedah, to determine the sub-surface temperature of the thermal springs based on silica content. The results obtained for reservoir temperatures ranged from 125ºC to 166ºC (Table 1). Present re-calculations of the sub-surface temperatures are also presented in Table 2. It seems that the previous calculations are similar results to quartz geothermometers by Fournier and Potter (1982) and Fournier (1977). The chalcedony geothermometers too bear encouraging results which most of it exceeds 100ºC and up to 142.4ºC, for the listed locations (refer Table 1 for the thermal springs locations).

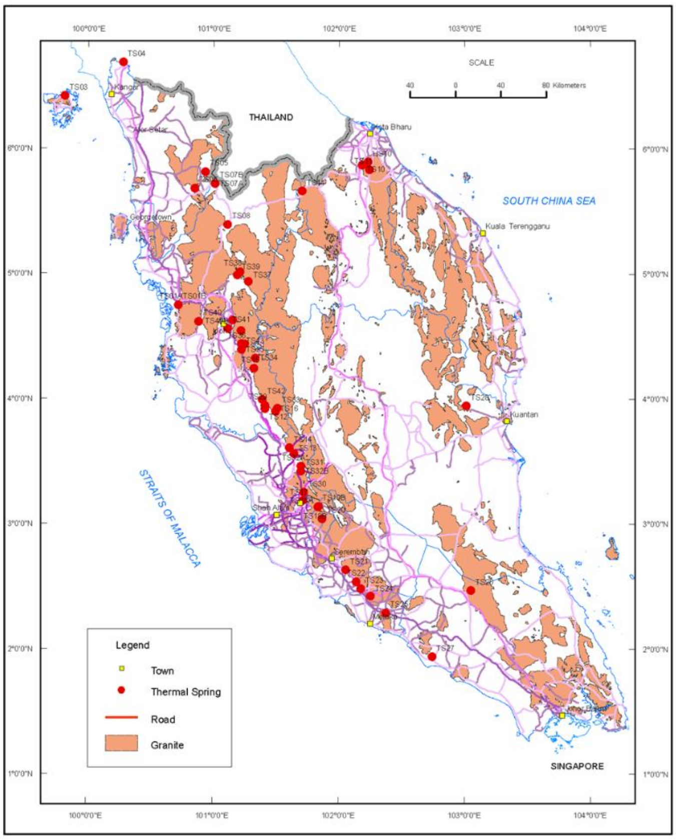

Figure 1: Location map of all thermal springs in Peninsular Malaysia (compiled from previous works).

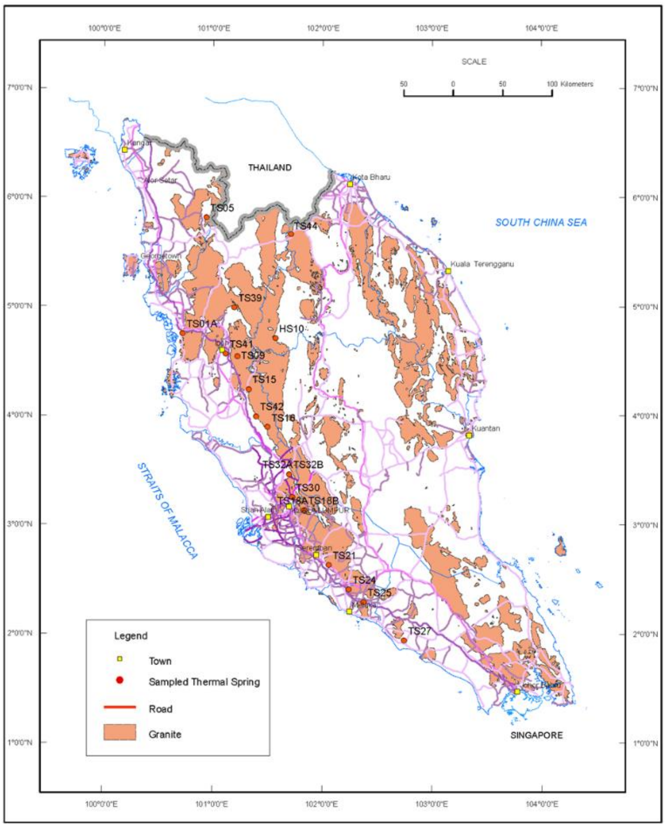

Figure 2: Location map of shortlisted and visited thermal springs in Peninsular Malaysia.

Table 1. Re-calculated sub-surface temperatures for several other thermal springs using several quartz and chalcedony geothermometers for Ho C.S. (1979).

Location	Surface T°C	Resevoir Temperature after Ho (1979)		Newly re-calculated Resevoir Temperatures, based on author's calculations				
		T Reservoir SiO2,	SiO_2 mg/l	T Quartz (F&P,82)	T Quartz (A,85)	T Chalcedony. (Ar,83) 25-180°C	T Chalcedony. (F77)	T quartz, F77, NO STEAM LOSS
Air Panas Keroh	43	154	135.0	154.9	149.0	126.9	130.0	154.7
Kg Sira, Gerik	58	134	95.0	134.5	131.5	106.1	107.3	134.3
Kg Air Panas Gerik	43	166	161.0	166.0	158.3	138.2	142.4	165.6
Batu 9, Trong, Taiping	49	nd	nd	nd	nd	nd	nd	nd
Kg Jeliang, Kuala Kangsar	40	nd	nd	nd	nd	nd	nd	nd
Tambun, Ipoh	63	136	99.0	136.8	133.5	108.4	109.9	136.6
Kramat Pulai, Ipoh	48	147	119.0	147.3	142.6	119.2	121.6	147.1
Ulu Kg Estate, Gopeng	42	<120	66.0	115.5	114.5	86.7	86.4	115.2
Kg Ulu Geroh, Gopeng	38	<125	71.0	119.1	117.8	90.4	90.4	118.9
Sg. Periah, Sg. Siput South	52	low	44.0	96.4	96.6	67.3	65.6	95.9
Sg. Batang Padang, Tapah	41	<125	75.0	121.9	120.4	93.2	93.5	121.7
Batu 7, Tapah	61	143	113.0	144.3	140.0	116.1	118.2	144.1
Kg. Air Panas, Ulu Slim, Tg. Malim	92	138	103.0	139.0	135.4	110.7	112.3	138.9
Kuala Bersih,Ulu Slim, Tg Malim	49	140	107.0	141.2	137.3	112.9	114.7	141.0
Kg. Legong, Baling	63	164	158	164.8	157.3	137.0	141.1	164.4
Kg. Sira Ko, Baling	28	136	100.0	137.3	134.0	109.0	110.5	137.2
Kg. Tas, Baling	40	nd	nd	nd	nd	nd	nd	nd
Kg. Air Hangat, P. Langkawi	44	nd	nd	nd	nd	nd	nd	nd

1.2 Evaluation

The dertermination of sub-surface temperatures were done by using the several cations and silica geothermometers, such as the quartz and chalcedony, Na/K and Na-K-Ca. The T-chalcedony geothermometers were used based on the fact that majority of the waters are non-equilibrated or partially equilibrated/ partially matured. The calculations of sub-surface temperatures by using cation geothermometers such as Na-K and Na-K-Ca were also done, but they are actually mainly for matured/equilibrated waters, or a higher enthalpy systems, where the usage of these cation geothermometers are more reliable. The quartz geothermometers (SiO_2), are recommended for geothermal systems having subsurface temperatures of more than 180°C (and this is usually a higher enthalpy systems).

The silica contents in a system are susceptible to dilution or precipitations, but for a higher enthalpy systems, the usage of the SiO_2 geothermometers are more reliable. So the usage of SiO_2 geothermometers are to be used in a careful manner. The silica contents in the waters (of < 150°C reservoir temperatures) are most likely governed by the chalcedony solubility in the waters.

In this report, since the chalcedony geothermometers (introduced by Fournier 1977) are not reflective of the thermal spring sub-surface temperatures, the T-quartz (by Fournier & Potter 1982), Na/K (by Fournier 1979) and Na-K-Ca (also by Fournier 1979), were considered. The amorphous silica (chalcedony) contents in the thermal springs were probably diluted or precipitated within the systems, therefore the sub-surface temperature results are lower than expected. The highest results for the T-chalcedony are 129.5°C for HS10 Lojing (see Table 2). The cations geothermometers (Na-K and Na-K-Ca) calculated results are reliable for TS01A Trong Taiping and TS27 Gerisek Johor, for they are Cl matured waters and partially equilibrated waters, and also for TS32B Batang Kali Selangor, which fall in the Cl maturity level.

Generally, the subsurface temperature results obtained from this study warrants further explorations..

Table 2. A summary of the calculated reservoir temperatures (by the author) for the selected thermal springs in Peninsular Malaysia

Nos.	Sample ID	Sample Location	Fournier (1977)	Fournier & Potter (1982)	Fournier (1979)	
			T chalcedony °C	T quartz, No Steam Loss °C	T Na/K °C	T Na-K-Ca °C
1	TS 01A(HS)	Trong, Taiping	105.1	132.4	180.3	166
2	TS05(HS)	Ulu Legong, Baling.	92.4	120.8	199.7	165
3	TS09(HS)	S.Pulai/Lubuk Timah	53.1	84.1	n.d.	208
4	HS10(HS)	Lojing Roadside	129.5	154.2	160.0	145
5	TS32B(HS)	Sg Tamu, Batang Kali	n.d.	n.d.	n.d	201
6	TS18A(HS)	Dusun Tua (riverside)	103.4	130.8	150.5	135
7	TS18B(HS)	Dusun Tua (upperside)	96.4	124.4	154.9	136
8	TS21(HS)	Pedas, Negri Sembilan	88.0	116.7	193.5	145
9	TS25(HS)	Kg. Air Panas, Jasin	97.2	125.1	145.8	133
10	TS30(HS)	Batu 9, Gombak	96.4	124.4	181.3	143
11	TS24(HS)	Kg. Gadek, Alor Gajah	79.5	108.9	161.9	142
12	TS39(HS)	Sg. Danak, Lasah	83.0	112.1	141.8	134
13	TS42(HS)	Sg. Kelah, Tg. Malim	84.7	113.7	157.6	146
14	TS44(HS)	Bendang Lawa, Jeli	56.2	87.1	133.7	115
15	TS15(HS)	Kg. Batu 7, Tapah	75.7	105.3	150.7	132
16	TS16(HS)	Kg. Air Panas,Ulu Slim	108.0	134.9	153.7	136
17	TS27(HS)	Parit Gerisek, Johor	95.0	123.1	176.4	164
18	HS06	Lojing, Kelantan	124.8	150.1	157.1	142
19	HS07	Lojing, Kelantan	93.5	121.7	150.0	135
20	HS08	Lojing, Kelantan	96.4	124.4	139.3	125
21	HS10	Lojing, Kelantan	129.5	154.2	160.0	145
22	HS13	Lojing, Kelantan	83.9	112.9	127.3	120
23	HS16	Lojing, Kelantan	94.2	122.4	151.9	136

2.0 SCOPE OF STUDY

The scope of study for the geothermic investigations in Peninsular Malaysia includes evaluationon the thermal springs and to determine or estimate its reservoir temperatures by using several chemical geothermometers and previous geochemistry data collected by the JMG since 1980s.

3.0 METHODOLOGY

The study generally involved:

i) Desktop study which includes data capture from published and unpublished works for the use in literature study on geothermal or thermal springs in Peninsular Malaysia.

ii) Assessment on the available data such as surface temperature, geology, chemistry of thermal waters, chemical geothermometry etc.

iii) Site verification and determining the upflow/outflow of thermal springs.

iv) Assessment and results interpretations

v) Surface geological assessments by using available maps and satellite data.

4.0 GENERAL GEOLOGY

Geothermal fluids may evolve through three geological processes or mechanisms:

i) Intrusion and cooling of magmas in the water bearing shallow crust

ii) Deep circulation of meteoric water in areas with high or normal heat flow

iii) High heat flow in areas with confined aquifers capped by a heat-insulating blanket of low heat-conductive rock.

The granite batholith (silicic) rock intrusions within the Main Range in the Peninsular Malaysia, provide a good heat source for the thermal springs, because they are viscous and generally intrude as large bulbous masses that may take a hundred thousand to a million years or more to cool. The heating mechanism of thermal springs in the Peninsular Malaysia is interpreted as deep circulation of water and/or high heat flow into confined aquifers capped by an insulating blanket of overlying sediment. The TS01A thermal spring in the Trong, Taiping Perak area, form a sediment filled basin probably bounded by unexposed faults within the basin margins. Rocks forming the basement of the sediment filled Trong area are interpreted as similar rock type to the granite that exposed in its eastern flank mountainous area. The TS27 thermal spring in the Gerisek area, Johor is similar to the TS01A. Both of these thermal springs may have seawater intrusions. A suitable geophysical investigation, followed by drilling, may confirm this postulation. In general, a probable graben-like structure with thick basin fill, pointing towards deep circulation, may be interpreted as the most likely heat source for most of the thermal spring areas.

Heat is not the only requirement for a geothermal resource. Hot water must be stored in rock/aquifer and must be easily extracted from that aquifer/rock. In other words, the rock has to be porous and permeable. Lithology of the host rocks, hydrologic character, and geometry of the geothermal resources may be the most pertinent geological parameters controlling the geothermal reservoirs in the Peninsular Malaysia.

4.1 Rock Chemistry

Large numbers of whole-rock silicate analyses are available on granites of Peninsular Malaysia. Some of the analyses are given in Table 3. It is clearly seen that the underlying rocks content are SiO_2, which present about 70% average of weight percentage.

Compositions of the geothermal fluids are controlled by temperature-dependent reactions between minerals and fluids. The factors affecting the formation of hydrothermal minerals are:

i. Temperature

ii. Pressure

iii. Rock Type

iv. Permeability

v. Fluid Composition

vi. Duration of Activity

The effect of rock type are most pronounced at low temperatures and insignificant above 280^{o}C.

Table 3. Chemical Analyses of selected granites and metamorphic rocks (extracted from Gobett and Hutchison, 1973)

	Weight Percentage(%)							
	i	**ii**	**iii**	**iv**	**v**	**vi**	**vii**	**viii**
SiO2	73.90	73.40	71.58	74.40	71.5	71.3	57.8	52.39
Al2O3	13.20	12.90	12.96	13.50	15.7	12.7	15.2	13.76
TiO2	0.20	0.26	0.66	0.23	0.02	0.53	0.68	1.50
Fe2O3	1.05	1.03	0.61	0.86	0.43	1.68	1.00	0.76
FeO	0.93	1.58	3.12	0.81	0.98	3.56	4.71	9.61
MnO	0.07	0.08	0.15	0.08	0.03	0.17	0.15	0.04
MgO	0.09	0.41	0.35	0.21	0.97	1.62	6.08	7.28
CaO	0.99	1.70	1.78	0.82	1.27	0.44	4.29	5.72
Na2O	3.62	3.30	3.39	3.75	4.36	1.39	1.80	2.05
K2O	4.99	4.45	5.03	4.90	3.84	2.79	6.29	4.08
P2O5	0.10	0.04	0.11	0.10	0.02	0.13	0.50	n.d.
CO2	0.03	0.03	n.d	0.06	0.08	0.24	0.04	0.32
H2O+	0.60	0.60	0.36	0.57	1.08	1.55	0.75	1.44
H2O-	0.22	0.26	0.12	0.11	0.22	0.17	0.23	
Total	99.99	100.04	100.22	100.40	100.50	98.27	99.52	99.50
Rock Type	Granites				Metamorphics			

n.d.: not determined

Descrciption to table 3 (see column numbers i-viii)

i. Dusun Tua, Ulu Langat Selangor, Rock Type: Muscovite-biotite Granite

ii. Tampin Quarry, Negri Sembilan, Rock Type: Porphyritic biotite Granite

iii. Kampar Road, near Kuala Dipang Perak, Rock Type: Porphyritic Granite

iv. New Jetty, Kuah, P.Langkawi, Rock Type: Biotite Granite

v. Biotite Gneiss, Sungai Anali, Kelantan

vi. Garnet-Mica Schist, Sungai Kenik, Kelantan

vii. Biotite Gneiss, Kupang, near Baling, Kedah

viii. Quartz Mica Schist, km5.6, Cameron Highlands road, Perak

At above 280^{o}C and at least as high as 350^{o}C, the typical stable mineral assemblages (in active geothermal systems) are independent of rock types and include:

i. Albite
ii. K-Feldspar
iii. Chlorite
iv. Fe-Epidote
v. Calcite
vi. Quartz
vii. Illite
viii. Pyrite

At lower temperatures, zeolite and clay minerals are found. At low permeabilities, equilibrium between rocks and fluids is seldom achieved. When permeabilities are relatively high and water residence times are long (months to years), water and rocks should reach equilibrium. At equilibration stage, ratios of cations in solution are controlled by temperature-dependent exchange reactions such as:

$$\mathbf{NaAlSi_3O_8\ (albite) + K^+ = KAlSi_3O_8\ (K\text{-}feldspar) + Na^+}$$

$$\mathbf{Keq.=[Na+]/[K+]}$$

Hydrogen ion activity (pH) is controlled by hydrolysis reactions, such as :

$$\mathbf{3KAlSi_3O_8(K\text{-}feldspar)+2H^+=KAl_3Si_3O_{10}(OH)_2(K\text{-}mica)+6SiO_2+2K^+}$$

$$\mathbf{Keq.=[K+]/[H+]}$$

Keq.=equilibrium constant, and square brackets indicate activities of dissolved species (activity is unity for pure solid phases)

5.0 RESULTS AND DISCUSSIONS

5.1 Water Chemistry of the Selected Thermal Springs

Previous results of the chemical analysis of waters collected by JMG are presented in Tables 4, 5 and 6. The pH values for thermal waters range from neutral to near neutral. The TDS (Total Dissolved Solids) contents of newly collected thermal waters range from 176 to 2685mg/l (Table 4) and TDS values from previous analysis range from 160 to 2,420 mg/l (Table 5). The electrical conductivities range from 202 to 4,300 uS/cm for the thermal waters (Tables 4 & 5).

The sodium in the thermal waters are derived from alteration of feldspars in granitic and schists. Clay minerals also enhance exchange of sodium with calcium.

Most of the samples are plotted near HCO_3 (bicarbonate) corner (Fig. 9). The high HCO_3 concentration in the thermal spring are due to reaction of CO_2-rich waters during the circulation of meteoric waters. The boron contents are attributed to the depth of water circulation or deeply seated magma body. In all the samples, the boron content is comparatively higher for TS01A Trong Taiping and TS27 Gerisek, Johor, i.e. 3.6 mg/l and 3.3mg/l respectively, whereas the rest of the thermal springs have lower contents, i.e. between 0.3 and 0.9 mg/l (Table 4).

The SiO_2 concentration in the thermal spring waters is between 10mg/l and 134 mg/l, being the highest from the HS10 thermal springs Lojing area. Silica addition to waters may be accomplished by alteration of silicate minerals or dissolution of quartz in alkaline conditions. SiO_2 contents of rocks in the vicinity of geothermal spring sites are about 71-74% weight percentage (Table 5).

The geochemical results of thermal springs were analysed and plotted by using ternary diagrams, such as Cl-SO_4-HCO_3 and Na-K-Mg for the types of geothermic water determination, and subsurface temperature estimation (Figs. 9 & 12).

Table 4. Geochemical analysis results of water samples from some thermal sites in the Peninsular Malaysia (Previous data by JMG).

Nos	SAMPLE ID	Boron	Total Solid (mg/l)	Dissolved Solid (mg/l)	pH	Turb. (NTU)	Conductivity (µs/cm)
1	TS 01A (HS)	3.6	3055	2685	7.1	15	3836
2	TS 05 (HS)	0.6	332	200	8.2	5	286
3	TS09 (HS)	0.9	289	189	7.7	10	270
4	HS 10 (HS)	0.6	269	179	9.2	3	256
5	TS 32B (HS)	0.9	302	176	7.6	5	251
6	TS 18A (HS)	0.8	317	181	8.6	6	258
7	TS 18B (HS)	0.4	290	180	8.6	9	257
8	TS 21 (HS)	0.5	322	211	7.7	8	302
9	TS 25 (HS)	1.2	377	251	8.1	10	358
10	TS 30 (HS)	0.6	271	181	7.4	6	259
11	TS 24 (HS)	0.8	325	214	8.1	8	306
12	TS 39b (HS)	0.5	285	202	8.5	6	289
13	TS 42 (HS)	0.5	266	141	8.7	5	202
14	TS 44 (HS)	0.7	336	244	8.1	10	349
15	TS 15 (HS)	0.3	218	127	7.4	8	181
16	TS 16 (HS)	0.5	263	158	8.7	6	225
17	TS 27 (HS)	3.3	3886	2972	7.0	20	4245

Table 5. Result of geochemical analysis (previous and original data collection is by JMG). The charge balances errors are less than 5% (±).

Nos	SampleID	Location	pH	Temp °C	Cond (µs/cm)	TDS (mg/l)	Na	K	Mg	Ca	Mn	Cl	SO_4	HCO_3	F	Al	As	SiO_2
1	TS 01A(HS)	Trong Taiping	7	47.5	3880	2268	635	40	1	98	0.1	1170	16	71	6.2	0.1	0.01	91.6
2	TS05(HS)	Baling Kedah	6.9	49.1	281	242	53	4.3	1	3.5	0.1	2	10	120	3.8	0.1	0.01	73.6
3	TS09(HS)	Gerik Perak	7	45.6	232	160	6.2	3.3	3.7	36	0.1	1	6	132	1	0.3	0.01	33.6
4	HS10(HS)	Lojing Kelantan	7	71.7	256	179	53	2.5	<0.1	1.5	<0.1	3	20	66	5.4	<0.1	0.08	134
5	TS32B(HS)	Hulu Tamu, Selangor	7.06	51.1	251	176	7.9	2.9	4.9	13	<0.1	36	14	28	<0.5	na	<0.1	10
6	TS18A(HS)	Hulu Langat, Selangor	6.86	78.8	240	218	54	2.2	1	2.6	0.1	1	8	118	9.1	na	0.03	89
7	TS18B(HS)	Hulu Langat, Selangor	6.83	71.2	259	216	55	2.4	1	3.4	0.1	1	8	121	9.3	0.1	0.15	79
8	TS21(HS)	Negri Sembilan	6.97	53.8	294	224	48	3.6	1	20	0.1	1	5	162	6.4	0.1	0.01	68
9	TS25(HS)	Melaka	7.01	57	341	274	74	2.8	1	4.3	0.1	5	7	149	12.8	0.1	0.01	80
10	TS30(HS)	Selangor	6.98	58.3	251	206	47	3	1	9.4	0.1	1	3	122	6..5	0.1	0.03	79
11	TS24(HS)	Melaka	6.99	51.5	301	224	66	3.2	1	4.2	0.1	3	4	156	10.4	0.1	0.01	58
12	TS39(HS)	Kelantan	7	57.3	275	206	62	2.2	1.8	1.7	0.1	2	17	129	6.2	0.3	0.01	62
13	TS42(HS)	Perak	6.98	96.3	202	174	44	2	0.5	0.8	0	1	8	89	4.3	0.1	0.01	64
14	TS44(HS)	Jeli, Kelantan	6	49.8	333	224	58	1.8	0.5	10	0	1	50	67	3.1	0.1	0.01	36
15	TS15(HS)	Perak	6.85	64.9	207	196	44	1.8	1	2.6	0.1	1	6	90	6.5	0.1	0	53.9
16	TS16(HS)	Perak	6.84	91.3	211	188	49	2.1	1	2.6	0.1	1	11	88	7.2	0.1	0.02	96
17	TS27(HS)	Batu Pahat, Johor	7	43.3	4300	2420	720	43	1.3	110	0.1	1230	124	70	5.6	0.1	0.01	77

(All results in mg/l except otherwise indicated, n.a.: not available)

Table 6. Results of analysis, taken from the previous geochemical analysis by JMG (incorporated from Azmi et al, 2002) for the Lojing area, Kelantan. The charge balance error are less than 5% (±).(All results in mg/l except otherwise indicated)

Nos.	Sample ID	Geology	pH	Cond (µs/cm)	TDS	Na	K	Mg	Ca	Cl	SO_4	HCO_3	Al	SiO_2
1	HS06	Granite	9.3	244	234	51	2.3	<0.1	1.6	2	20	57	<0.1	125
2	HS07	Granite	8.4	209	200	47	1.9	<0.1	1.9	2	14	100	<0.1	75
3	HS08	Granite	8.5	190	190	44	1.5	0.1	2.3	<1	12	92	<0.1	79
4	HS10	Granite	9.3	255	256	53	2.5	<0.1	1.5	3	20	66	<0.1	134
5	HS13	Granite	9.1	234	204	54	1.5	0.2	2.2	2	22	68	<0.1	63
6	HS16	Granite	8.5	210	201	48	2	<0.1	2	2	15	100	<0.1	76

5.2 Types of Geothermal Water.

Cl-SO_4-HCO_3 Ternary Diagram

Types of geothermic water play an important role in selecting type of geothermal plant for application. Results of Cl-SO_4-HCO_3 contents from the geochemical analysis (Table 7) were used to classify the geothermic groundwater by plotting the Cl^-, SO_4 and HCO_3 values on the Cl-SO_4-HCO_3 ternary diagram (Figs. 9 and 10). It is observed that there is no thermal water sample from the studied geothermal site falls within the SO_4 domain. Most of the thermal waters are fall within the HCO_3 domain of the ternary diagram, except for the TS01A from Trong Taiping, TS27 Gerisek from Johor and TS32B Batang Kali from Selangor that fall within the Cl^- corner (Fig. 9). The waters of TS44 Jeli, Kelantan and HS10 Lojing, Kelantan fall within the HCO_3 domain (Figs. 9 & 10). Data on Cl-SO_4-HCO_3 collected from Lojing area, Kelantan is shown in Table 8.

The thermal water that falls near the HCO_3 corner is not sufficiently mature and the HCO_3 could be mostly derived from CO_2-rich groundwater and possibly from magmatic activity. In the upper parts margins of geothermal systems, where thermal waters are mixed with cold waters, temperatures of the geothermal fluids with high bicarbonates and dissolved CO_2 contents are well below the boiling temperatures.

In the Cl-SO_4-HCO_3 ternary diagram, the higher contents of HCO_3 may indicate mixing of thermal spring waters with cold groundwaters (peripheral water) and may be due to the presence of carbonate rocks within or surrounding the area. The more chloride contents indicate the water is mature (Cl mature).

Table 7. Results of analysis for Cl-HCO_3-SO_4 contents.

Nos.	SampleID	StationID	Cl	SO_4	HCO_3	TOTAL	%HCO_3	%Cl	%SO_4
1	TS 01A(HS)	Trong	1170	16	71	1257	6	93	1
2	TS05(HS)	Ulu Legong	2	10	120	132	91	2	8
3	TS09(HS)	S.Pulai	1	6	132	139	95	1	4
4	HS10A(HS)	Lojing Roadside	3	20	66	89	74	3	22
5	TS32B(HS)	Sg Tamu, Batang Kali	36	14	28	78	36	46	18
6	TS18A(HS)	Dusun Tua	1	8	118	127	93	1	6
7	TS18B(HS)	Dusun Tua	1	8	121	130	93	1	6
8	TS21(HS)	Pedas	1	5	162	168	96	1	3
9	TS25(HS)	Kg. Air Panas, Jasin	5	7	149	161	93	3	4
10	TS30(HS)	Bt. 9, Gombak	1	3	122	126	97	1	2
11	TS24(HS)	Kg. Gadek, Alor Gajah	3	4	156	163	96	2	2
12	TS39(HS)	Sg. Danak, Lasah	2	17	129	148	87	1	11
13	TS42(HS)	Sg. Kelah, Tg. Malim	1	8	89	98	91	1	8
14	TS44(HS)	Bendang Lawa	1	50	67	118	57	1	42
15	TS15(HS)	Kg. Batu 7, Tapah	1	6	90	97	93	1	6
16	TS16(HS)	Kg. Air Panas, Hulu Slim	1	11	88	100	88	1	11
17	TS27(HS)	Parit Gerisek	1230	124	70	1424	5	86	9

(All results in mg/l except otherwise indicated)

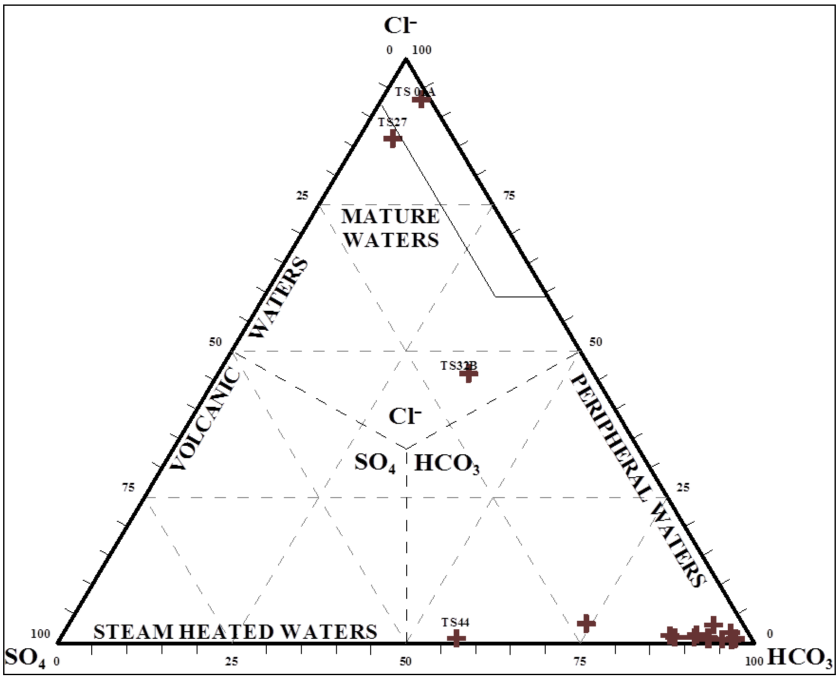

Figure 2. Ternary diagram for Cl-SO_4-HCO_3.

It is clearly shown in the diagram above that the TS01A Trong Taiping, TS27 Gerisek Johor, thermal springs are of the Cl^- mature waters. The TS32B Batang Kali thermal spring is also plotted in the Cl^- maturity area in the diagram. The rest of the samples are plotted in the HCO_3 corner and within the peripheral waters category.

Table 8. Results of analysis for Cl-SO_4-HCO_3 contents for Lojing area, Kelantan.

Nos.	SampleID	StationID	Location	Cl	SO_4	HCO_3	TOTAL	%HCO_3	%Cl	%SO_4
1	HS06	HS06	Lojing	2	20	57	79	72	3	25
2	HS07	HS07	Lojing	2	14	100	116	86	2	12
3	HS08	HS08	Lojing	<1	12	92	104	88	0	12
4	HS10	HS10	Lojing	3	20	66	89	74	3	22
5	HS13	HS13	Lojing	2	22	68	92	74	2	24
6	HS16	HS16	Lojing	2	15	100	117	85	2	13

(All results in mg/l except otherwise indicated)

The ternary diagram above showing that all the spring water samples from the Lojing area, Kelantan are plotted near the HCO_3 apex. The water types are likely of peripheral waters with some of it with little steam-heated components.

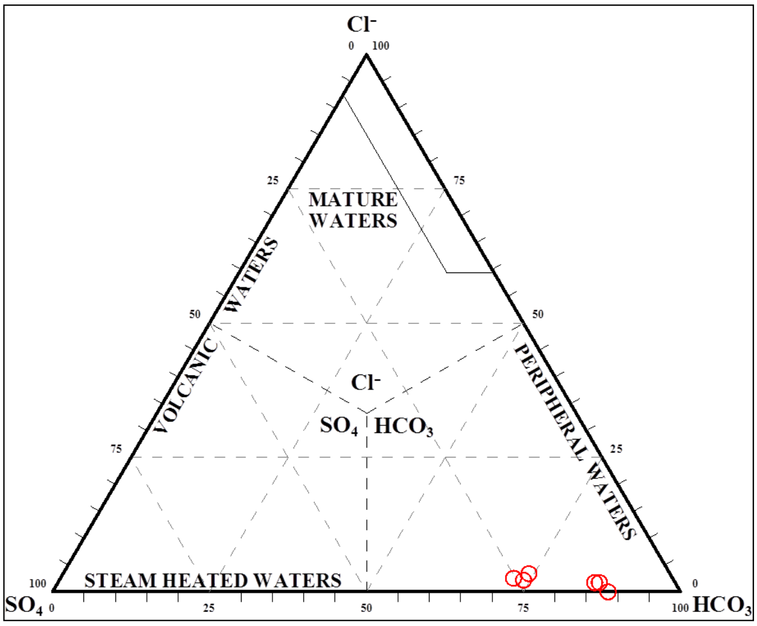

Figure 3. Ternary diagram for Cl-SO_4-HCO_3 collected from Lojing area, Kelantan.

5.3. RESEVOIR (SUB-SURFACE) WATER TEMPERATURE

Na-K-Mg Ternary Diagram and Geothermometry

In order to determine reservoir temperatures of the geothermal waters, chemical geothermometers were applied. Results of analysis for Na-K-Mg contents using Giggenbach Triangle are shown in Table 9. The overall possible reservoir (subsurface) temperatures for the 17 selected thermal springs are presented in Table 10. Of the silica geothermometers, the quartz and chalcedony geothermometers yield reservoir temperatures of 84.1-154.2°C and 53.1-129.5°C respectively. As suggested by Kharaka & Mariner (1988) and Giggenbach (1991), the silica solubility at temperatures below 180°C is governed by amorphous silica and/or chalcedony and, the quartz geothermometer might be unreliable. Based on ternary diagram Na-K-Mg proposed by Giggenbach (1988), all the data points fall at the apex of Mg of the immature waters and the lower part of partially equilibrated or mixed waters (Fig. 11). However, waters from the Lojing area, Kelantan are consistent in both the Cl-SO_4-HCO_3 and Na-K-Mg ternary diagrams (Figs. 10 & 12).

From the Na-K-Mg ternary diagram (the Giggenbach Triangle), if the water sample are plotted near to Mg corner, it is also indicating that the thermal fluids are a mixture of cold groundwaters. If the samples are relatively high in Mg concentrations, this is due to the HCO_3^- type of water, and it is actually difficult to estimate the reservoir temperature.

Since most of the waters are immature, the solute geothermometry is not likely to yield meaningful equilibration temperatures. In this case, the only option is to use the silica geothermometers. By using the chalcedony geothermometer, the temperature estimates, which range from 53.1 to 129.5°C, are non-reflective of the geothermal system reservoir temperatures in the Peninsular Malaysia (see Table 10). This are due to cases such as the Dusun Tua area (TS18A and B) and in the Ulu Slim area TS16 and Sg. Kelah area TS42 thermal springs, in which the reservoir temperatures are lower or very close to the measured surface temperatures of the thermal springs. This is probably due to dilution or precipitations of the SiO_2 content during ascent of geothermal fluids to the surface. Therefore, it is suggested, that the quartz geothermometer (by Fournier 1977), cations geothermometers of Na/K and Na-K-Ca are to be used only for general estimate prior to drilling, to confirm the exact reservoir temperatures; as the results obtained are reflective of the granitic hosted geothermal systems. As for the TS01A Trong Taiping and TS27 Gerisek Johor, the Na/K and

Na-K-Ca may be accepted, due to their partial equilibration and Cl^- maturity, but still all the sub-surface temperatures are merely estimated reservoir temperatures. Drilling may confirm the exact temperatures.

The summary of all the calculated reservoir (sub-surface) temperatures, using the suitable geothermometers are shown in shaded column of Table 10.

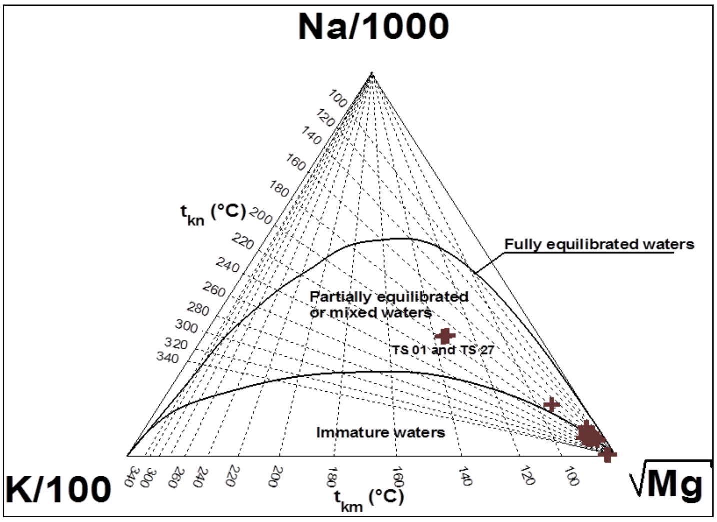

Figure 4. Na-K-Mg ternary diagram (Giggenbach Triangle) introduced by Giggenbach, 1988.

Figure 11 above showing that all samples collected fall into the Mg apex indicating that the waters are immature. Except for the samples TS01A Trong and TS27 Gerisek, they are partially equilibrated waters. In this case the cation geothermometers may be applied to TS01A and TS27.

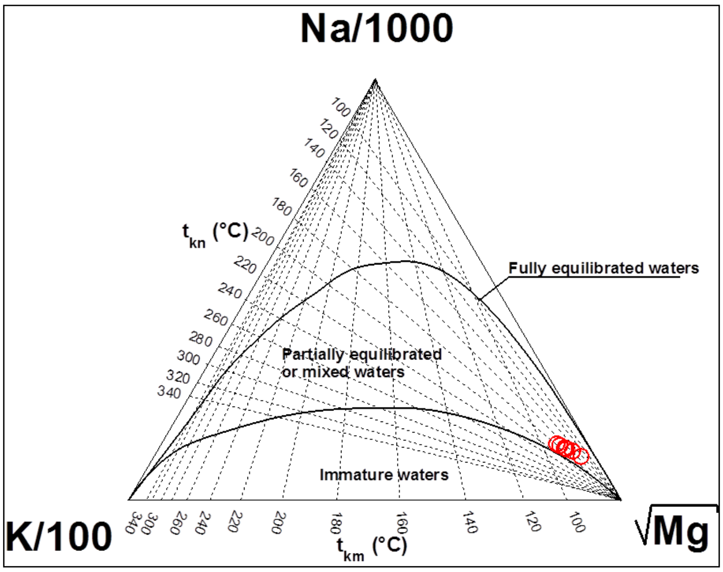

Figure 5. Na-K-Mg ternary diagram for waters collected from Lojing area, Kelantan.

The diagram shows that the position of waters collected from the Lojing area are consistent in both Na-K-Mg ternary diagram (above) and the Cl-SO_4-HCO_3 ternary diagram (Fig. 10). The samples are of Mg apex plot and in this case, the chalcedony geothermometer is the most suitable for this water type but it still depends on the dilution or precipitation of the SiO_2 in the thermal systems.

Summary of possible subsurface temperatures of the thermal springs obtained from selected geothermometers is shown in Table 11.

Table 9. Result of analysis for Na-K-Mg contents using Giggenbach Triangle.

Nos.	Sample ID	Na	K	Mg	Na/1000	K/100	sqrt Mg	Total	% (Na/1000)	% (K/100)	% (sqrt Mg)	Total%
1	TS 01A(HS)	635	40	1	0.635	0.4	1.00	2.04	31	20	49	65
2	TS05(HS)	53	4.3	1	0.053	0.043	1.00	1.10	5	4	91	94
3	TS09(HS)	6.2	3.3	3.7	0.0062	0.033	1.92	1.96	0	2	98	98
4	HS10A(HS)	53	2.5	0.1	0.053	0.025	0.32	0.39	13	6	80	87
5	TS32B(HS)	7.9	2.9	4.9	0.0079	0.029	2.21	2.25	0	1	98	99
6	TS18A(HS)	54	2.2	1	0.054	0.022	1.00	1.08	5	2	93	95
7	TS18B(HS)	55	2.4	1	0.055	0.024	1.00	1.08	5	2	93	95
8	TS21(HS)	48	3.6	1	0.048	0.036	1.00	1.08	4	3	92	94
9	TS25(HS)	74	2.8	1	0.074	0.028	1.00	1.10	7	3	91	94
10	TS30(HS)	47	3	1	0.047	0.03	1.00	1.08	4	3	93	95
11	TS24(HS)	66	3.2	1	0.066	0.032	1.00	1.10	6	3	91	94
12	TS39(HS)	62	2.2	1.8	0.062	0.022	1.34	1.43	4	2	94	96
13	TS42(HS)	44	2	0.5	0.044	0.02	0.71	0.77	6	3	92	95
14	TS44(HS)	58	1.8	0.5	0.058	0.018	0.71	0.78	7	2	90	94
15	TS15(HS)	44	1.8	1	0.044	0.018	1.00	1.06	4	2	94	96
16	TS16(HS)	49	2.1	1	0.049	0.021	1.00	1.07	5	2	93	96
17	TS27(HS)	720	43	1.3	0.72	0.43	1.14	2.29	31	19	50	66

(All results in mg/l except otherwise indicated)

Table 10. Overall subsurface temperatures results obtained by calculation using several methods. Shaded columns indicate suitable geothermometers.

Nos.	**Sample ID**	**Sample Location**	**T Na/K (Ar83, 25-250^oC) ^OC**	**T Na/K (Giggenbach, 1988) ^OC**	**T Na/K (T76) ^OC**	**T Na/K (Fournier, 1979) ^OC**	**T quartz (F&P,82) ^OC**	**T quartz (A,85) ^OC**	**T chalc. (Ar83, 25-180^oC)**	**T chalcedony. (Fournier, 1977) ^OC**	**T quartz (Fournier,77), No Steam Loss ^OC**	**T Na-K-Ca (Fournier, 1979) /aq ^OC**
1	TS 01A(HS)	Trong, Taiping	152.2	197.9	142.7	180.3	132.5	129.8	104.0	105.1	132.4	166
2	TS05(HS)	Ulu Legong, Baling.	174.6	216.1	166.1	199.7	121.0	119.5	92.3	92.4	120.8	165
3	TS09(HS)	S.Pulai/Lubuk Timah	n.d	n.d.	n.d.	n.d.	84.7	85.1	55.5	53.1	84.1	208
4	HS10A(HS)	Lojing Roadside	129.1	178.7	118.7	160.0	154.5	148.6	126.4	129.5	154.2	145
5	TS32B(HS)	Sg Tamu, Batang Kali	n.d	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	201
6	TS18A(HS)	Dusun Tua (riverside)	118.4	169.5	107.6	150.5	130.9	128.4	102.4	103.4	130.8	135
7	TS18B(HS)	Dusun Tua (upperside)	123.3	173.8	112.8	154.9	124.6	122.8	96.0	96.4	124.4	136
8	TS21(HS)	Pedas, Negri Sembilan	167.4	210.3	158.5	193.5	117.0	115.9	88.2	88.0	116.7	145
9	TS25(HS)	Kg. Air Panas, Jasin	113.2	165.0	102.3	145.8	125.3	123.4	96.7	97.2	125.1	133
10	TS30(HS)	Batu 9, Gombak	153.3	198.8	143.8	181.3	124.6	122.8	96.0	96.4	124.4	143
11	TS24(HS)	Kg. Gadek, Alor Gajah	131.2	180.4	120.9	161.9	109.2	108.7	80.3	79.5	108.9	142
12	TS39(HS)	Sg. Danak, Lasah	108.8	161.2	97.7	141.8	112.4	111.7	83.5	83.0	112.1	134
13	TS42(HS)	Sg. Kelah, Tg. Malim	126.3	176.3	115.9	157.6	114.0	113.1	85.1	84.7	113.7	146
14	TS44(HS)	Bendang Lawa, Jeli	99.9	153.5	88.6	133.7	87.6	88.0	58.4	56.2	87.1	115
15	TS15(HS)	Kg. Batu 7, Tapah	118.7	169.8	107.9	150.7	105.7	105.5	76.7	75.7	105.3	132
16	TS16(HS)	Kg. Air Panas,Ulu Slim	122.0	172.7	111.4	153.7	135.1	132.0	106.7	108.0	134.9	136
17	TS27(HS)	Parit Gerisek, Johor	147.7	194.3	138.0	176.4	123.3	121.6	94.6	95.0	123.1	164
18	HS06	Lojing, Kelantan	125.8	175.8	115.3	157.1	150.3	145.1	122.1	124.8	150.1	142
19	HS07	Lojing, Kelantan	117.8	169.1	107.1	150.0	121.9	120.4	93.2	93.5	121.7	135
20	HS08	Lojing, Kelantan	106.1	158.9	95.0	139.3	124.6	122.8	96.0	96.4	124.4	125
21	HS13	Lojing, Kelantan	92.8	147.3	81.4	127.3	113.2	112.4	84.3	83.9	112.9	120
22	HS16	Lojing, Kelantan	120.0	170.9	109.3	151.9	122.6	121.0	93.9	94.2	122.4	136

Table 11. Summary of subsurface temperatures of thermal springs obtained from selected geothermometers.

Nos.	Sample ID	Sample Location	Measured Surface Temperature	T chalcedony (Fourier, 1977)	T quartz (Fourier, 1977), No Steam Loss	T Na/K (Fourier, 1979)	T Na-K-Ca (Fourier, 1979) /aq
1	TS 01A(HS)	Trong, Taiping	47.5	105.1	132.4	180.3	166
2	TS05(HS)	Ulu Legong, Baling.	49.1	92.4	120.8	199.7	165
3	TS09(HS)	S.Pulai/Lubuk Timah	45.6	53.1	84.1	n.d.	208
4	HS10(HS)	Lojing Roadside	71.7	129.5	154.2	160.0	145
5	TS32B(HS)	Sg Tamu, Batang Kali	51.1	n.d.	n.d.	n.d	201
6	TS18A(HS)	Dusun Tua (riverside)	78.8	103.4	130.8	150.5	135
7	TS18B(HS)	Dusun Tua (upperside)	71.2	96.4	124.4	154.9	136
8	TS21(HS)	Pedas, Negri Sembilan	53.8	88.0	116.7	193.5	145
9	TS25(HS)	Kg. Air Panas, Jasin	57	97.2	125.1	145.8	133
10	TS30(HS)	Batu 9, Gombak	58.3	96.4	124.4	181.3	143
11	TS24(HS)	Kg. Gadek, Alor Gajah	51.5	79.5	108.9	161.9	142
12	TS39(HS)	Sg. Danak, Lasah	57.3	83.0	112.1	141.8	134
13	TS42(HS)	Sg. Kelah, Tg. Malim	96.3	84.7	113.7	157.6	146
14	TS44(HS)	Bendang Lawa, Jeli	49.8	56.2	87.1	133.7	115
15	TS15(HS)	Kg. Batu 7, Tapah	64.9	75.7	105.3	150.7	132
16	TS16(HS)	Kg. Air Panas,Ulu Slim	91.3	108.0	134.9	153.7	136
17	TS27(HS)	Parit Gerisek, Johor	43.3	95.0	123.1	176.4	164
18	HS06	Lojing, Kelantan	64.0	124.8	150.1	157.1	142
19	HS07	Lojing, Kelantan		93.5	121.7	150.0	135
20	HS08	Lojing, Kelantan		96.4	124.4	139.3	125
21	HS13	Lojing, Kelantan		83.9	112.9	127.3	120
22	HS16	Lojing, Kelantan	60.0	94.2	122.4	151.9	136

(All results in ^{o}C, n.d. not determined)

6.0 CONCLUSIONS

The information on the reservoirs temperatures gathered from this study by using previous data (since 1980s) is very useful before further detailed study that will involve more expensive tools or techniques to study the potentials of the geothermal resources in Peninsular Malaysia.

Figures 6, 7 and 8 may be used as general conceptual models for the thermal springs occurrence in granitic systems in the Peninsular Malaysia. The thermal springs produced mainly within fault planes, and mainly within a contact zones of granite and metasediments.

Based on the preliminary assessments done for the selected thermal sites in the Peninsular Malaysia, the most promising sites, based on sub-surface or reservoirs temperatures, are the Hulu Slim (TS16), Lojing (HS10), Sg. Kelah(TS42), Trong (TS01A), Dusun Tua (TS18A&B) and Hulu Tamu (TS32B) and Lubuk Timah (TS09). As for the TS01A Trong Taiping and TS27 Parit Gerisek, Johor; a further study needs to be carried to ascertain the occurrence of seawater intrusions in the area.

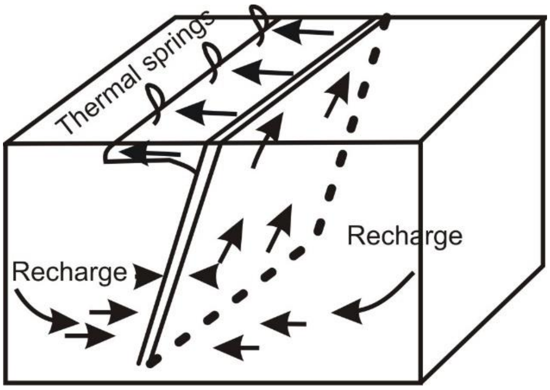

Figure 6. Conceptual model for geothermal resources in granitic systems.

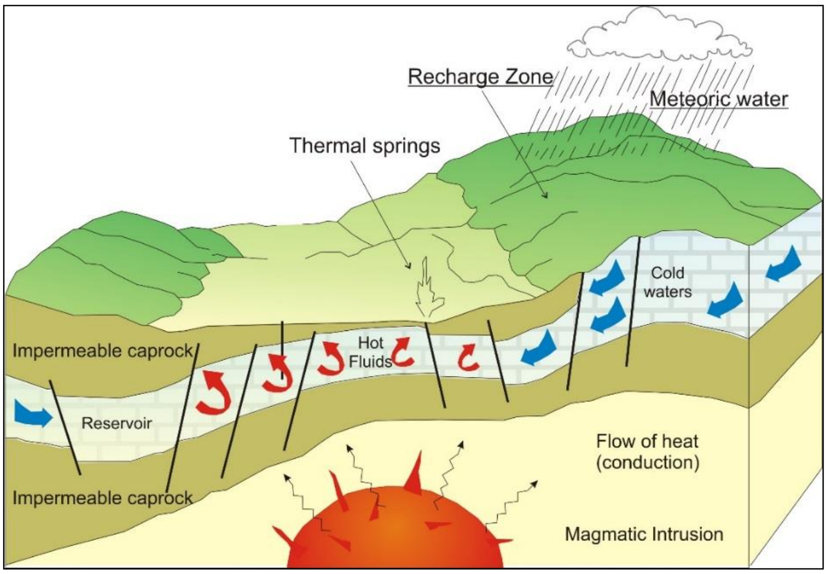

Figure 7. An example of general conceptual model for Hulu Slim, Perak and Lojing, Kelantan, within a granitic geothermal resources system (unknown source).

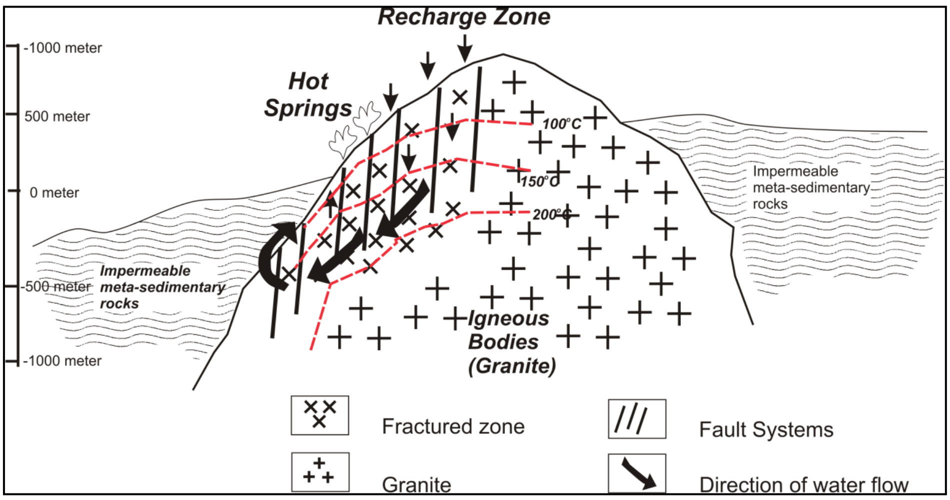

Figure 8. An example of general conceptual model for Hulu Slim, Perak, within a granitic geothermal resources system.

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